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Transmutation of Nuclear Wastes by Accelerator Driven System (ADS)

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Background

- Concern to radioactive waste management has been increasing in Japan.

➔ **Transmutation technology** is drawing the attention from public, media and politicians.

- JAEA has been studying this technology for more than 20 years since the former institutes (JAERI and PNC/JNC).

- The Ministry of Education, Culture, Sports Science and Technology (MEXT) in Japan has launched a **Working Party to review Partitioning and Transmutation Technology** in August, 2013, and issued an interim report in November, 2013.

Major Long-lived Nuclides in Spent Fuel

Actinides

Nuclide	Half-life (year)	Dose coefficient (μSv/kBq)	Mass (per 1tHM)
U-235	0.7B	47	10kg
U-238	4.5B	45	930kg

Trans-uranic elements (TRU)

Nuclide	Half-life (year)	Dose coefficient (μSv/kBq)	Mass (per 1tHM)
Pu-238	87.7	**230**	0.3kg
Pu-239	24k	**250**	6kg
Pu-240	6.6k	**250**	3kg
Pu-241	14.3	4.8	1kg

Minor actinides (MA)

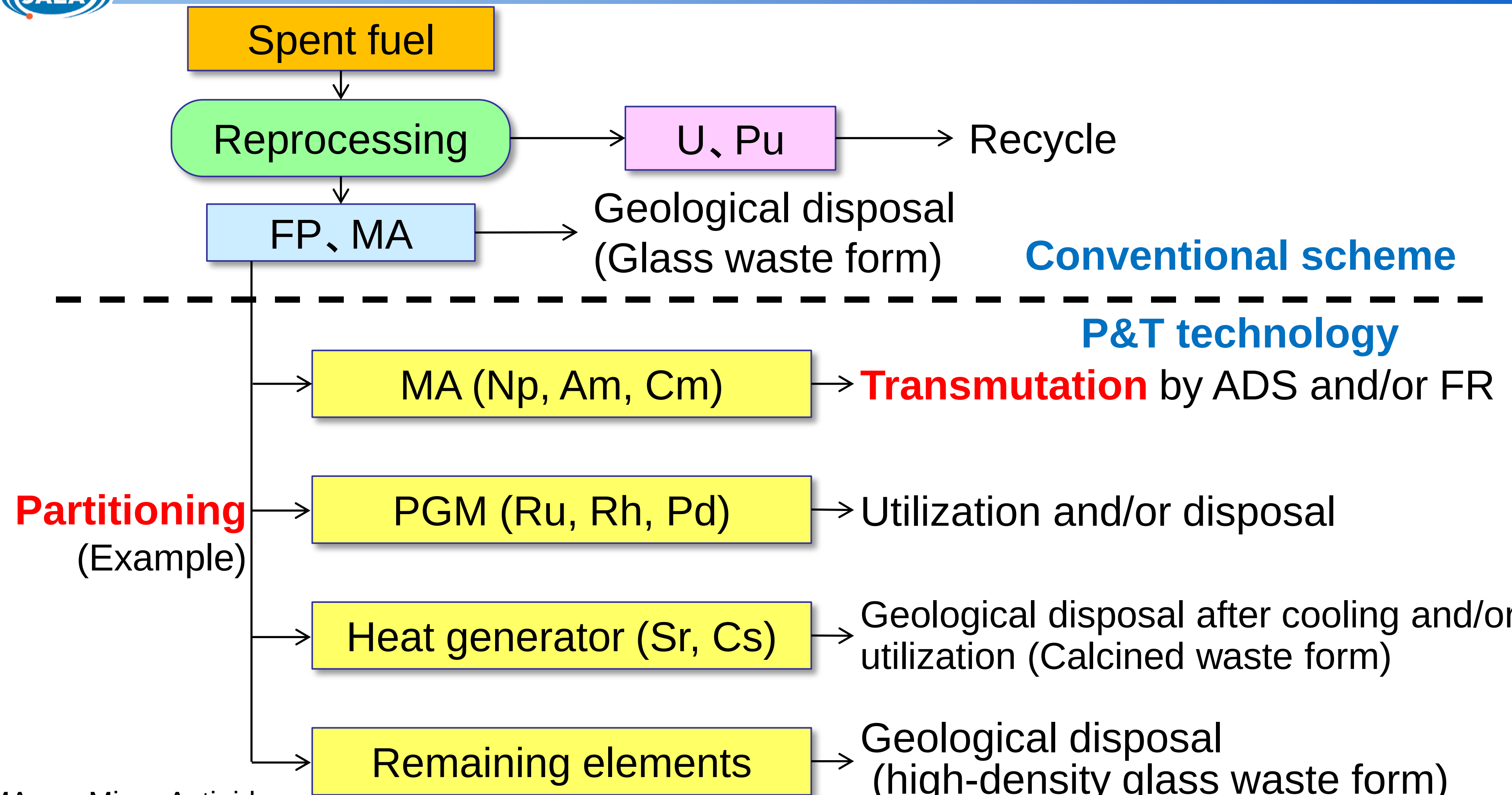
Nuclide	Half-life (year)	Dose coefficient (μSv/kBq)	Mass (per 1tHM)
Np-237	2.14M	**110**	0.6kg
Am-241	432	**200**	0.4kg
Am-243	7.4k	**200**	0.2kg
Cm-244	18.1	**120**	60g

Fission products (FP)

Nuclide	Half-life (year)	Dose coefficient (μSv/kBq)	Mass (per 1tHM)
Se-79	0.3M	2.9	6g
Sr-90	28.8	28	0.6kg
Zr-93	1.53M	1.1	1kg
Tc-99	0.21M	0.64	1kg
Pd-107	6.5M	0.037	0.3kg
Sn-126	0.1M	4.7	30g
I-129	15.7M	**110**	0.2kg
Cs-135	2.3M	2.0	0.5kg
Cs-137	30.1	13	1.5kg

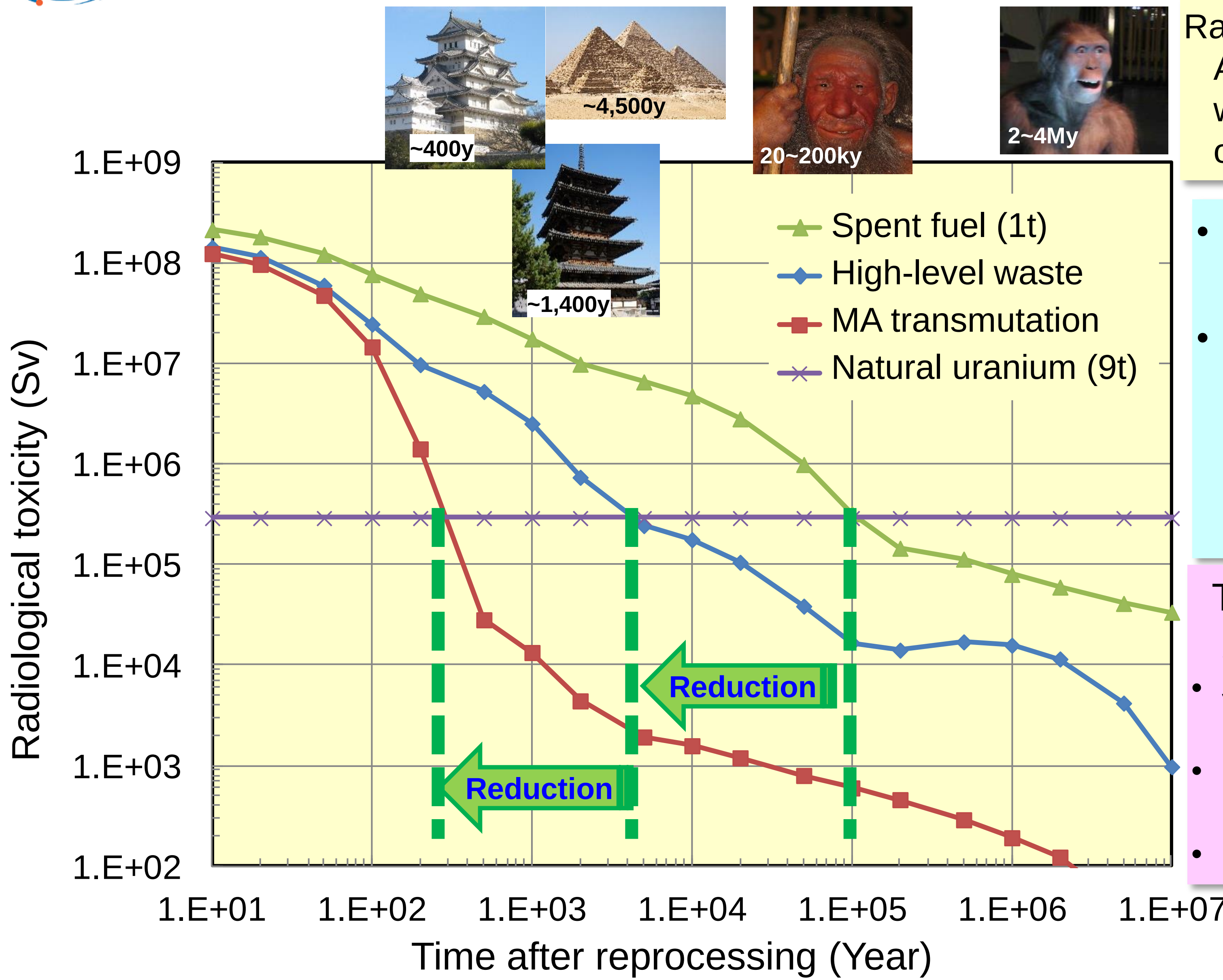
Dose Coefficient:
Committed dose (Sv) per unit intake (Bq), indicating the magnitude of influence of radioactivity to human body. α-activity is more influential than β,γ-activity.

Partitioning and Transmutation (P&T)



MA: Minor Actinides
FP: Fission Products
PGM: Platinum Group Metal
FR: Fast Reactor
ADS: Accelerator Driven System

Reduction of Radiological Toxicity by P&T



Radiological Toxicity:
Amount of radioactivity weighted by dose coefficient of each nuclide.

- Normalized by 1t of spent fuel.
- 9t of natural uranium (NU) is raw material of 1t of low-enriched uranium including daughter nuclides.

Time period to decay below the NU level:

- Spent fuel **100,000y**

↓

- High-level waste **5,000y**

↓

- MA transmutation **300y**

Compact Disposal by Coupling with Long-term Storage

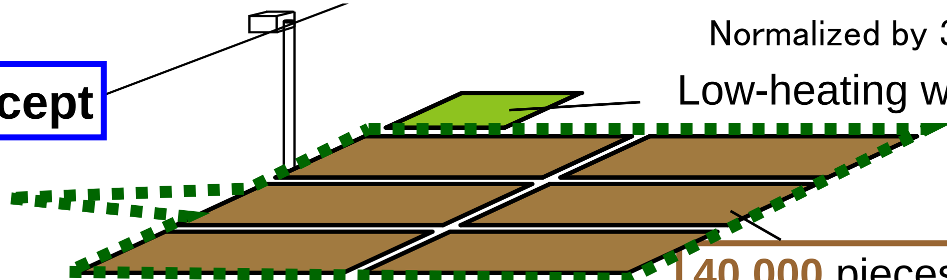
Normalized by 32,000tHM of 45GWd/t spent fuel

CT: Cooling time before disposal

Conventional Concept

1.8 km²

(Vertical emplacement in crystalline rock)

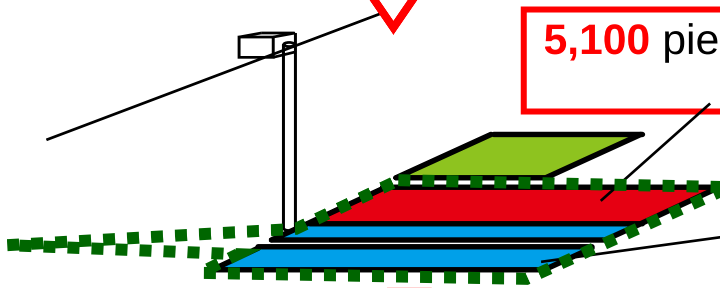


Low-heating wastes (0.13km²)

40,000 pieces of **glass waste forms** (1.8km²)
(CT: **50** y)

MA transmutation
+
FP Partitioning

0.41 km²

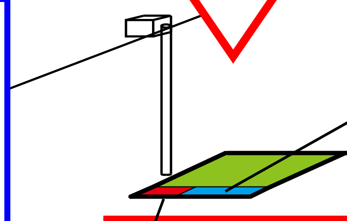


5,100 pieces of **Sr-Cs** calcined forms (0.23km²)
(CT: **130** y)

8,300 pieces of **highly-loaded glass** waste forms (0.18km²)
(CT: **5** y)

MA transmutation
+
FP Partitioning
+
Long-term storage of Sr+Cs

0.015 km²



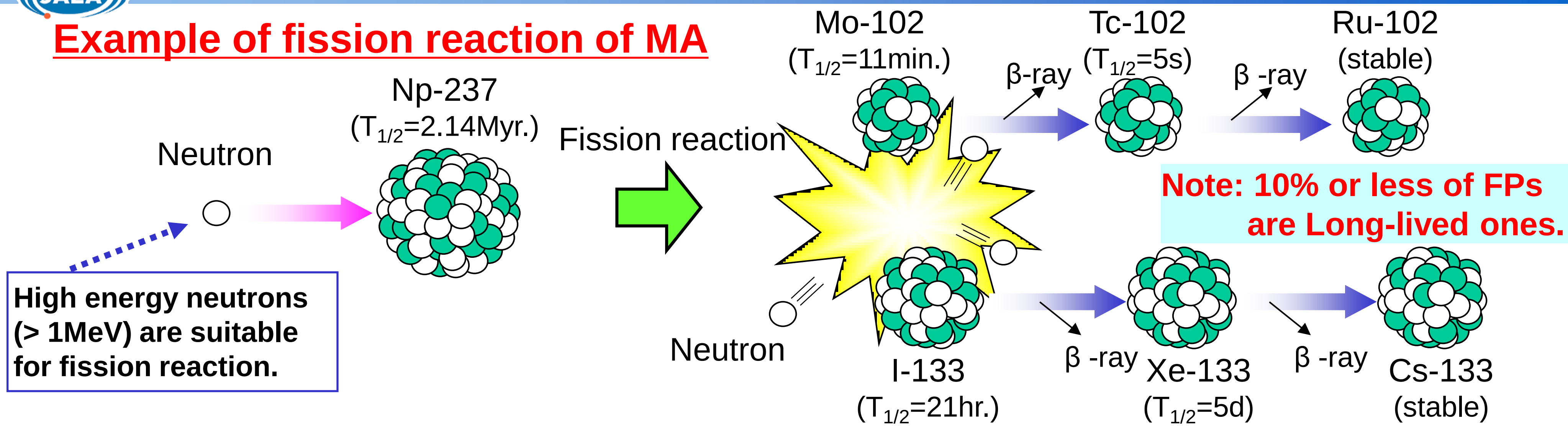
8,300 pieces of **highly-loaded glass** waste forms (0.01km²)
(CT: **45** y)

5,100 pieces of **Sr-Cs** calcined forms (0.005km²)
(CT: **320** y)

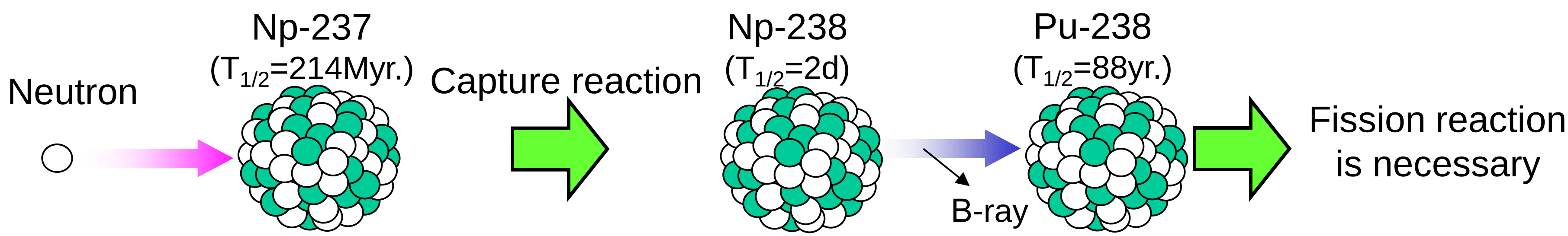
Ref. : K. Nishihara, et al., "Impact of Partitioning and Transmutation on LWR High-level Waste Disposal", J. Nucl. Sci. Technol., 45(1), 84-97 (2008).

How to Transmute MA and LLFP

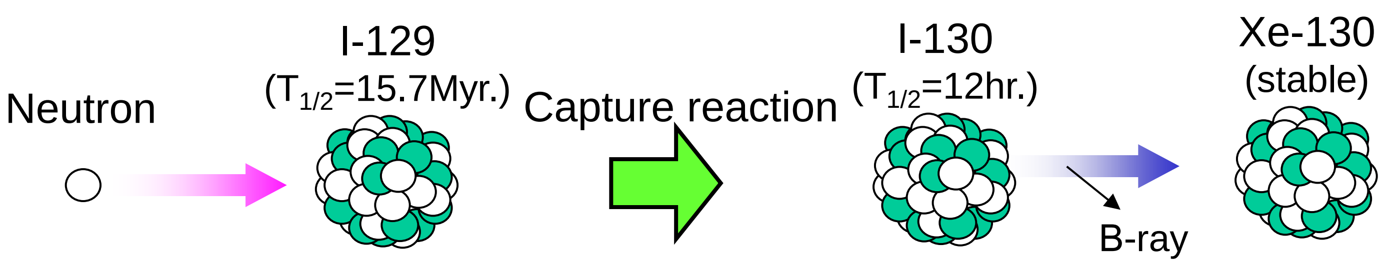
Example of fission reaction of MA



Example of capture reaction of MA

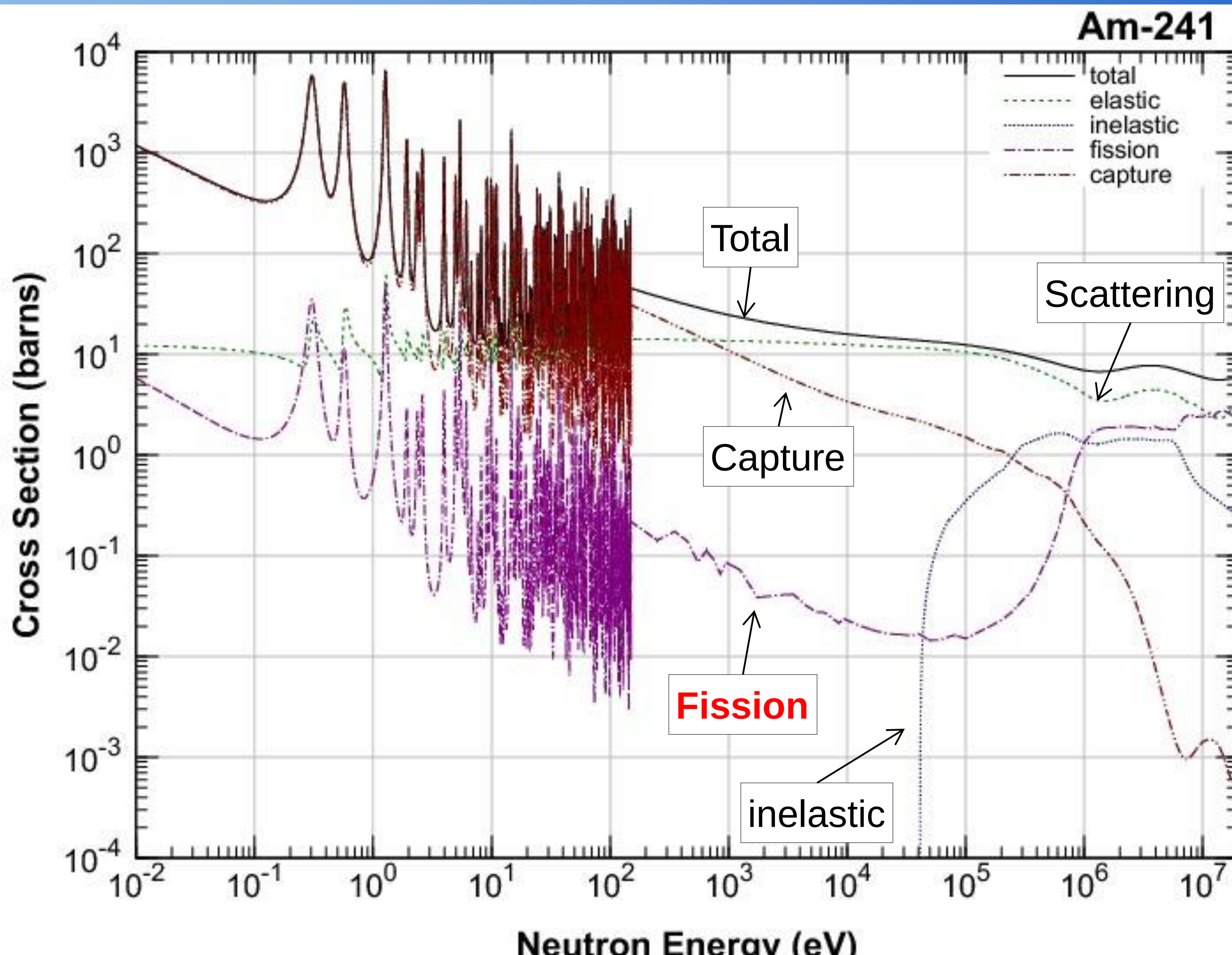


Example of capture reaction of LLFP



$T_{1/2}$: Half life

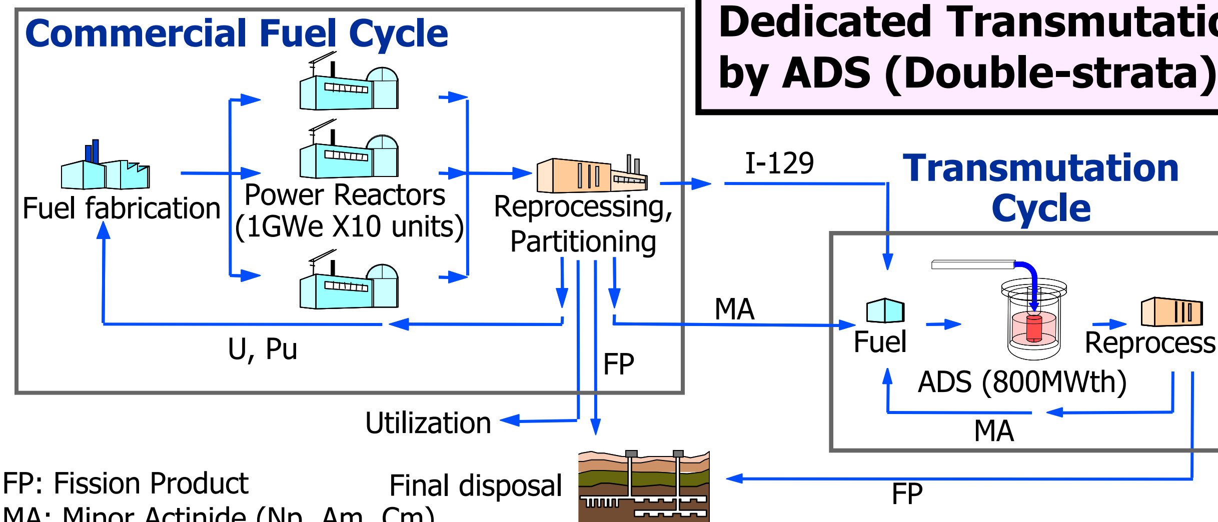
Cross Sections of Neutron-induced Reaction : Am-241



- Chain reactions of fission by fast neutrons are advantageous for transmutation of MA.

Two Types of Fuel Cycles for Partitioning and Transmutation Technology

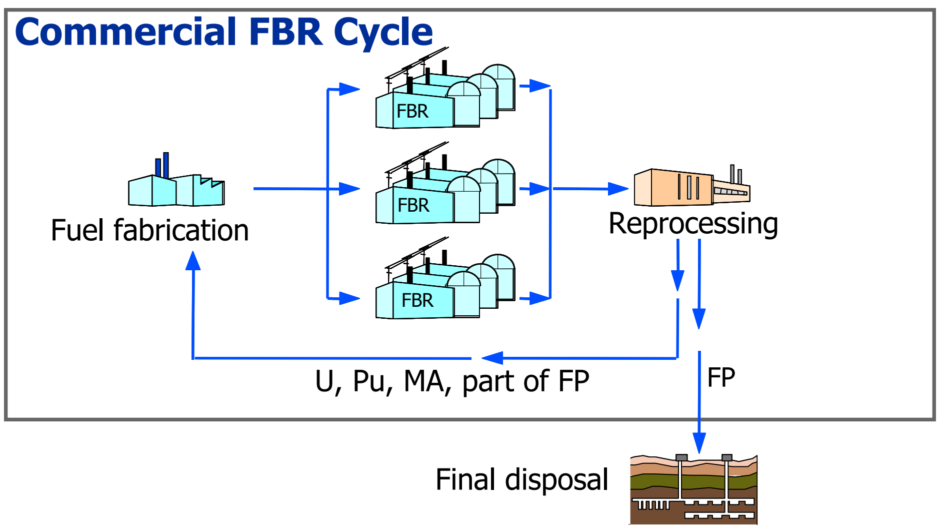
Dedicated Transmutation by ADS (Double-strata)



FP: Fission Product
MA: Minor Actinide (Np, Am, Cm)
ADS: Accelerator-Driven System
ABR: Actinide Burner Reactor

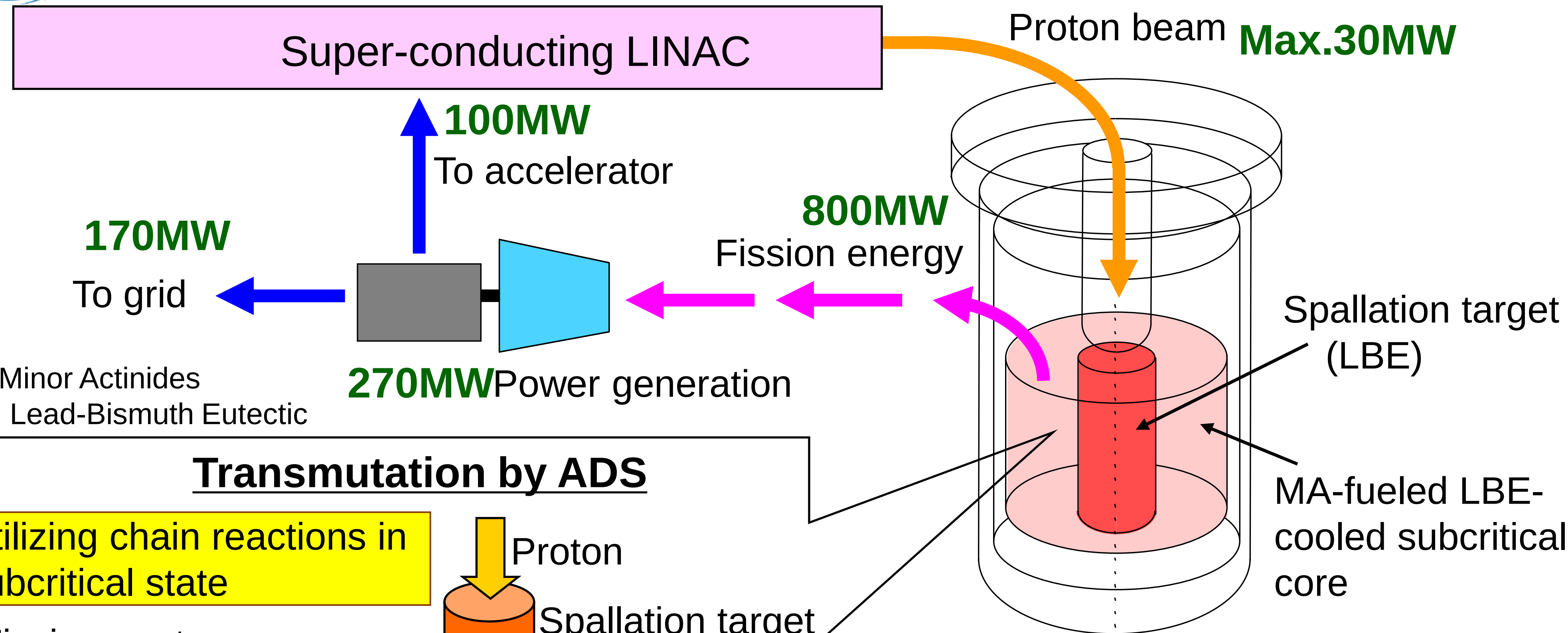
- Transmutation cycle is attached to commercial cycle.
- ADS or ABR is used as dedicated transmutation system.
- MA can be confined into a small cycle and transmuted efficiently.

Homogeneous Recycle in FBR

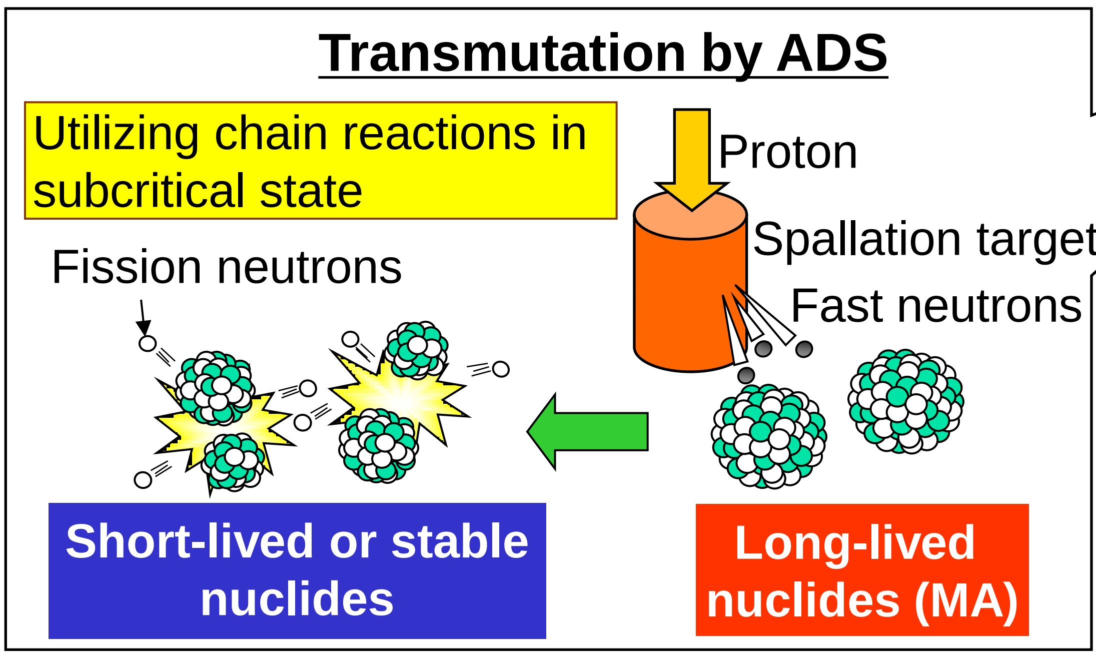


- MA is transmuted by commercial FBR power plants.
- 5% MA (max.) is added to conventional FR fuel (MOX, Metal, ...)

Accelerator Driven System (ADS) for MA Transmutation



MA: Minor Actinides
LBE: Lead-Bismuth Eutectic

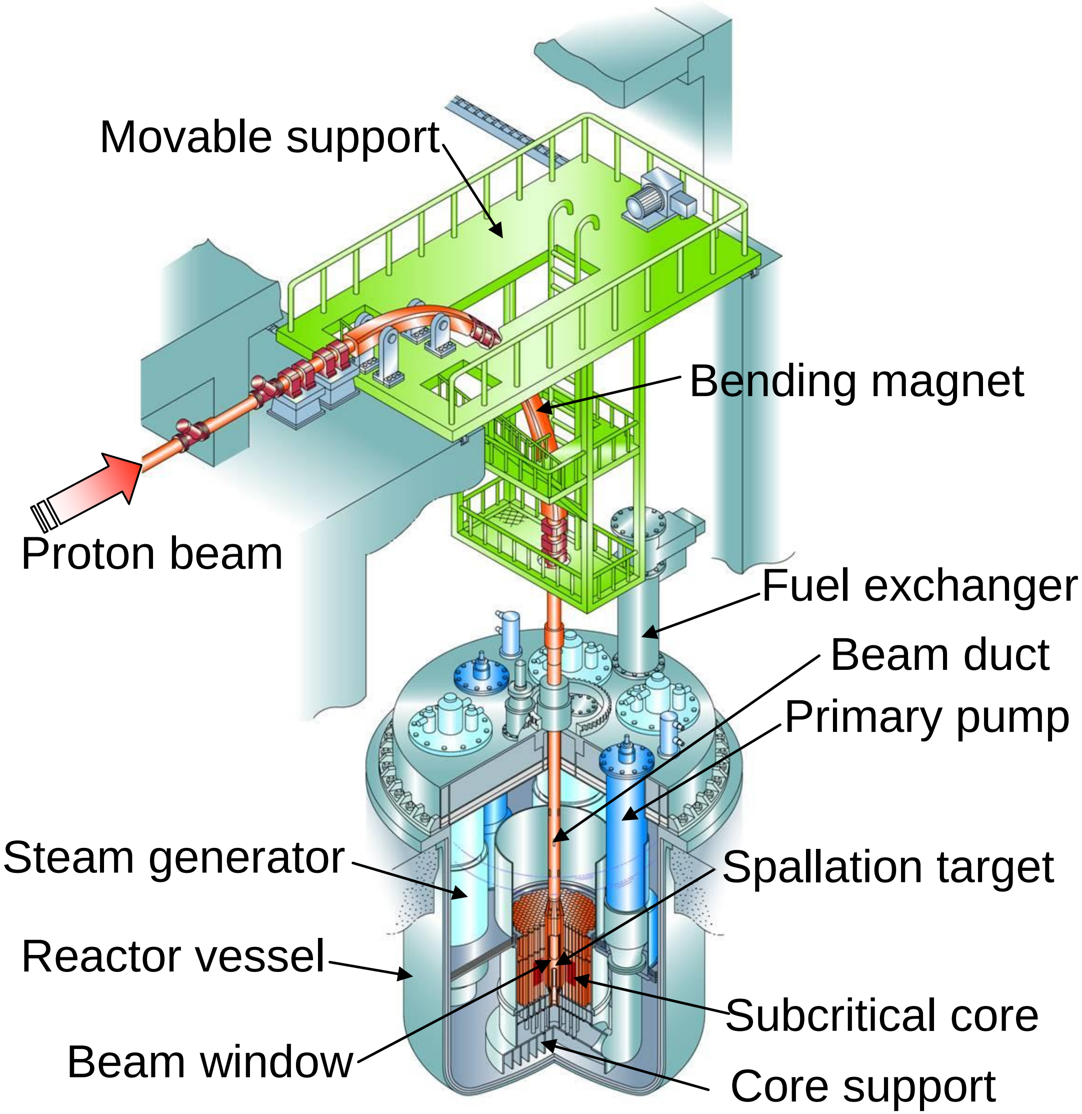


Characteristics of ADS:

- Chain reactions stop when the accelerator is turned off.
- LBE is chemically stable.
  ➔ **High safety can be expected.**
- High MA-bearing fuel can be used.
  ➔ MA from **10 LWRs** can be transmuted.

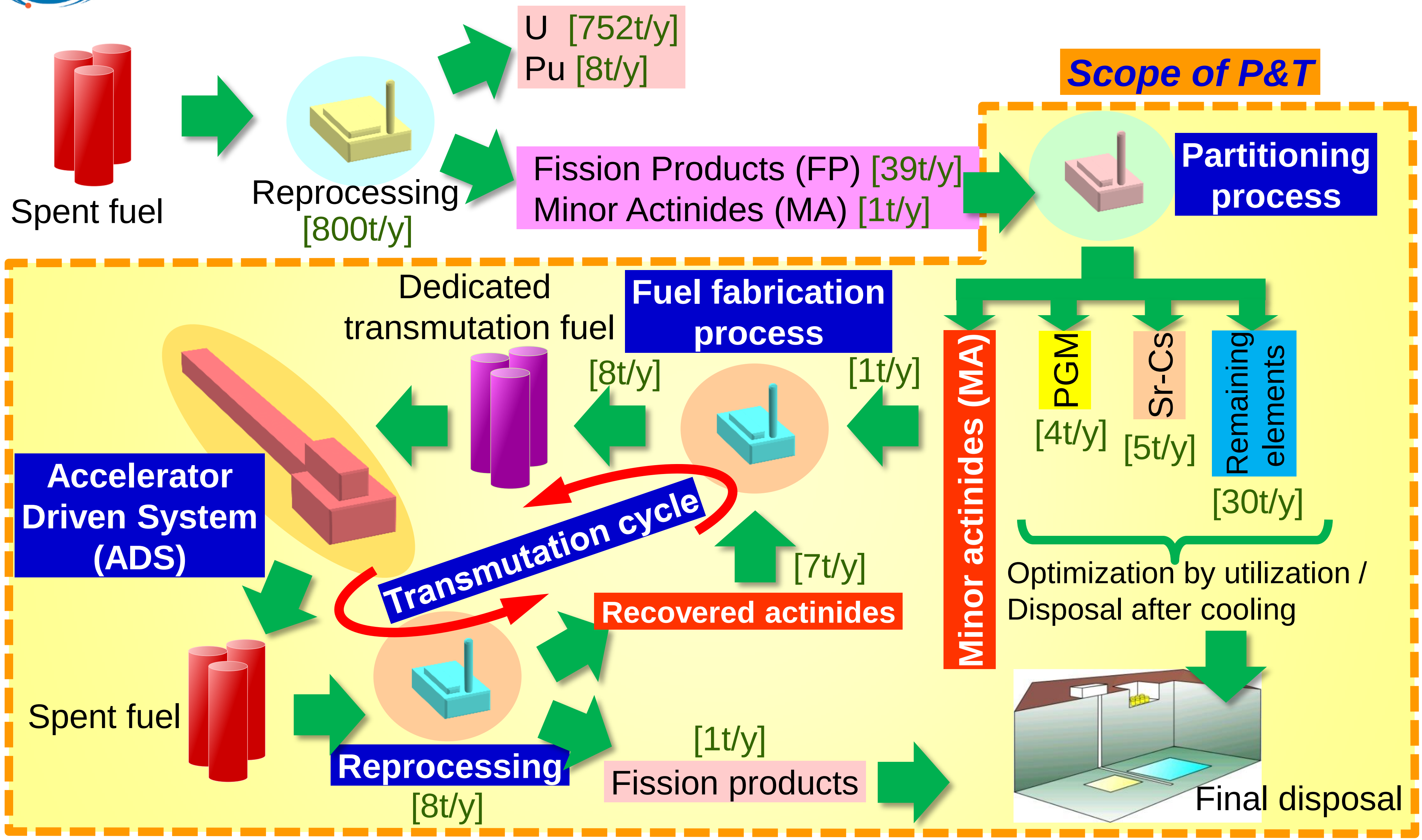
ADS Proposed by JAEA

- Proton beam : **1.5GeV**
- Spallation target : **Pb-Bi**
- Coolant : **Pb-Bi**
- Max. k_{eff} = 0.97
- Thermal output : **800MWt**
- MA initial inventory : 2.5t
- Fuel composition :
  (MA +Pu)Nitride + ZrN
- Transmutation rate :
  10%MA / Year
- 600EFPD, 1 batch



Conceptual view of 800 MWth LBE-cooled ADS

Components of Double-strata Fuel Cycle Concept



PGM: Platinum Group Metal

Technical Issues for ADS

J-PARC: Japan Proton Accelerator Research Complex
TEF-P: Transmutation Physics Experimental Facility
TEF-T: ADS Target Test Facility
SC-LINAC: Superconducting LINAC

•Accelerator

- R&D of SC-LINAC
- Reliability Assessment

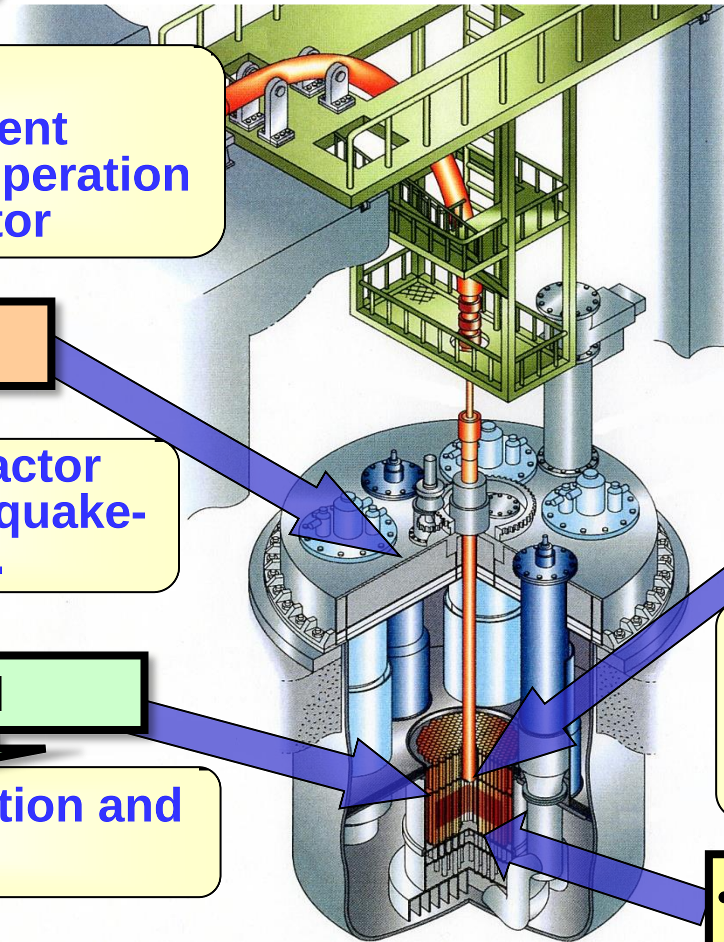
➔Construction and operation of J-PARC accelerator

•Structure

•Design study on reactor vessel, beam duct, quake-proof structure, etc.

•Fuel

•Fabrication, irradiation and reprocessing tests



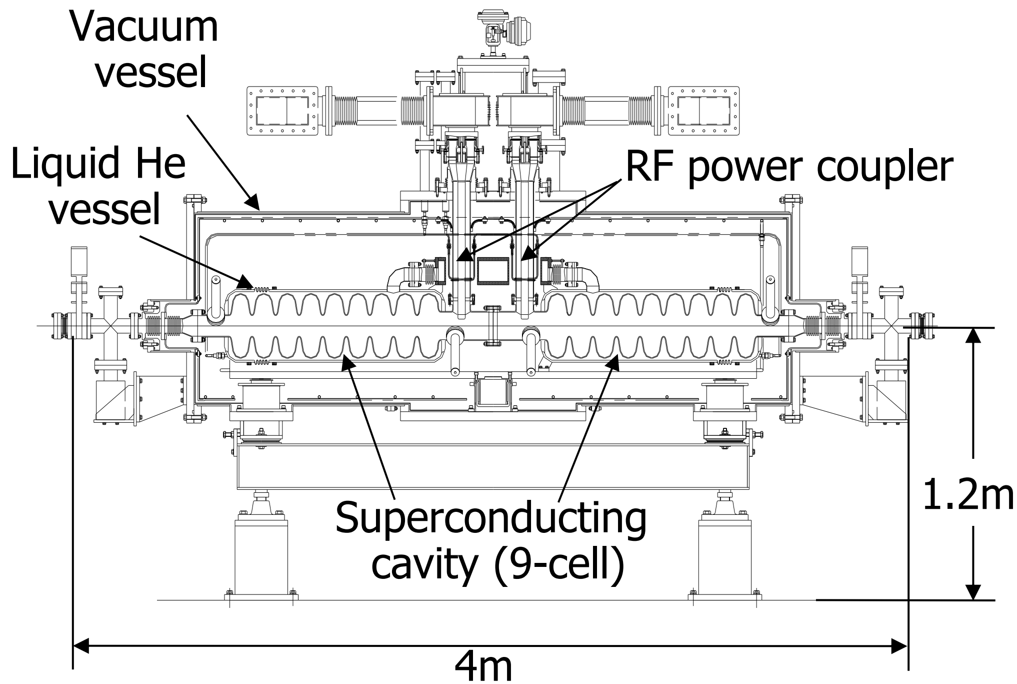
•R&D of Pb-Bi technology
➔Construction of TEF-T in J-PARC

•Spallation Target, Material
•Operation of Pb-Bi system

•Experiments in existing facilities and analyses
➔Construction of TEF-P in J-PARC

- **Reactor Physics**
- **Control of Subcritical System**

Development of Super-conducting LINAC



972 MHz Cryomodule

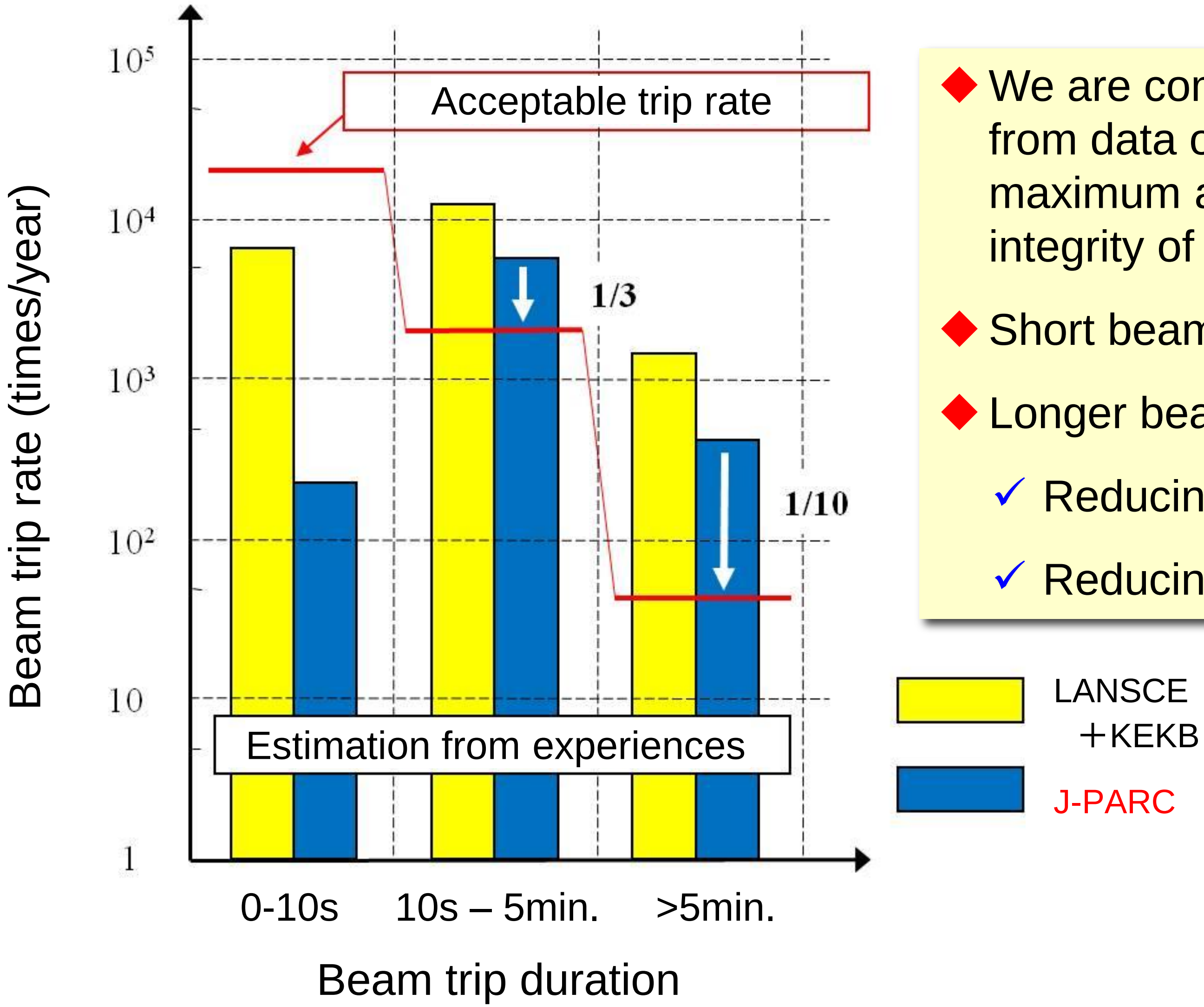
Superconducting cavity

Cryomodule

- **Cryomodule was designed to accept 927MHz RF wave and to be suitable for acceleration of 424MeV proton.**
- **Cool-down tests of prototype cryomodule was successfully carried out at 4.2 and 2.1K.**

Reliability of Accelerator

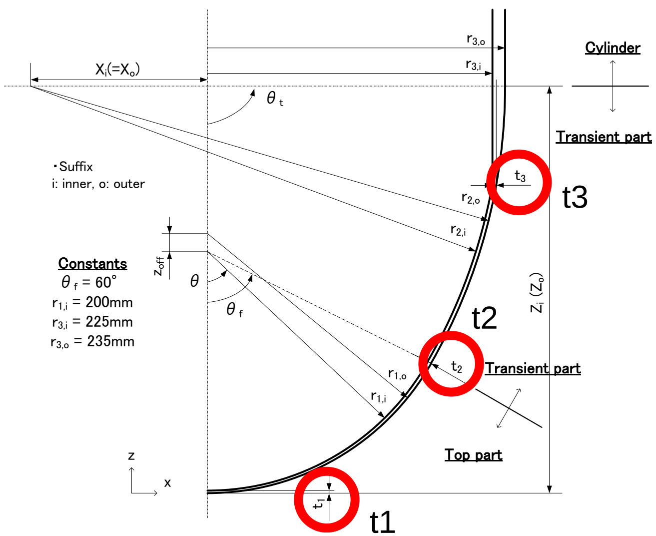
Number of beam trips per year (7,200 hours)

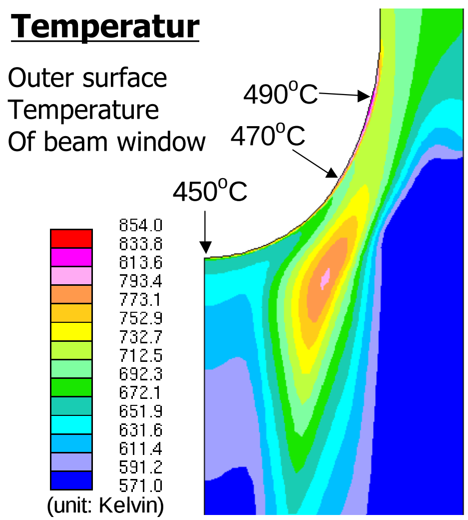


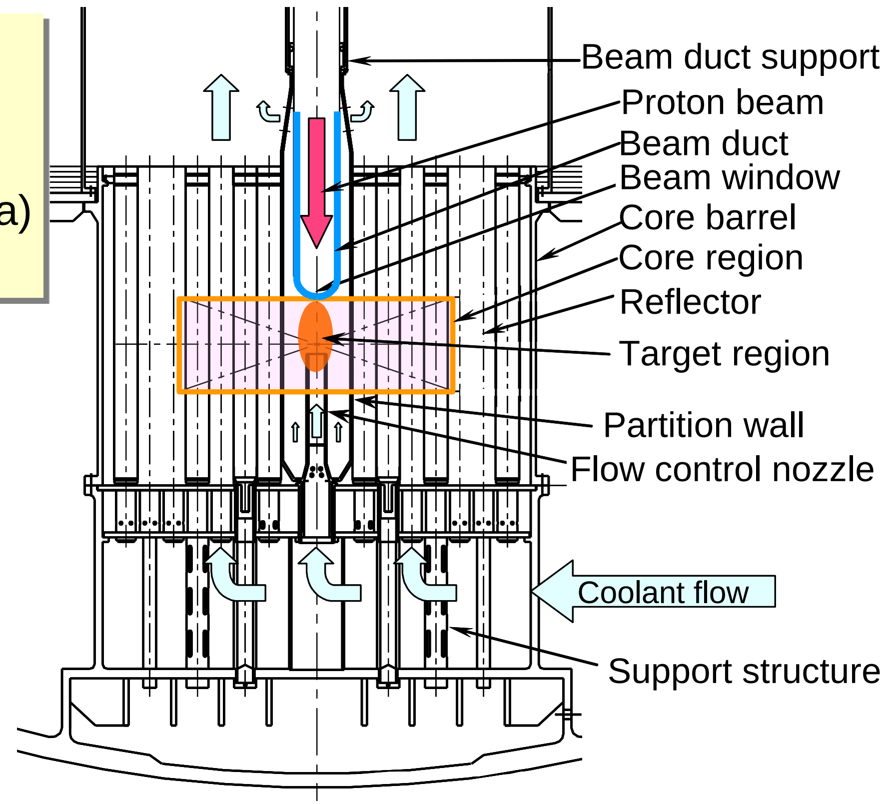
- We are comparing the trip rate estimated from data of existing accelerators and the maximum acceptable trips to keep the integrity of the ADS components.
- Short beam trip (<10s) can meet the cliteria.
- Longer beam trip should be decreased by:
  - ✓ Reducing the frequency and
  - ✓ Reducing the beam trip duration

Design of Beam Window

- Beam window is subjected to severe conditions:
  - ✓ High temperature
  - ✓ Corrosion and erosion by LBE
  - ✓ Pressure difference between vacuum and LBE (~0.8MPa)
  - ✓ Irradiation by protons and neutrons



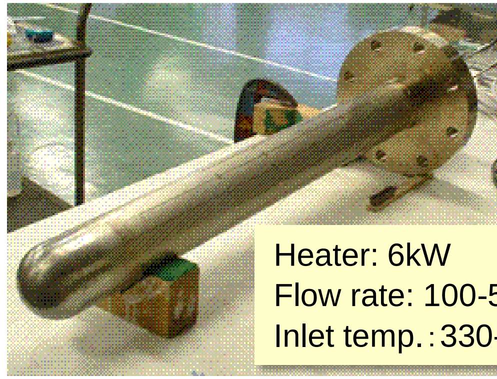




- Temperature at the outer surface of the window can be less than 500ºC.
- Buckling failure can be avoided by a factor of safety (FS)=3.
- ◆ The life time of the beam window should be evaluated from viewpoints of corrosion and irradiation. ➔ **necessity of irradiation data base.**

Mock-up Experiments for Beam Window Thermal-hydraulics

JLBL-3

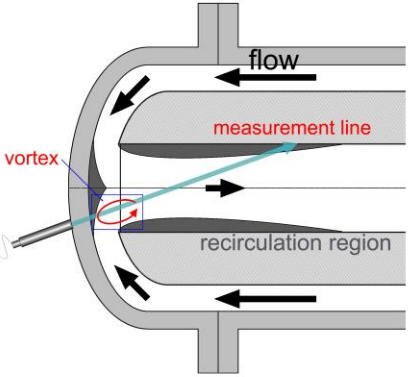


Heater: 6kW
Flow rate: 100-500 L/min.
Inlet temp.: 330-430ºC

Mock-up of beam window

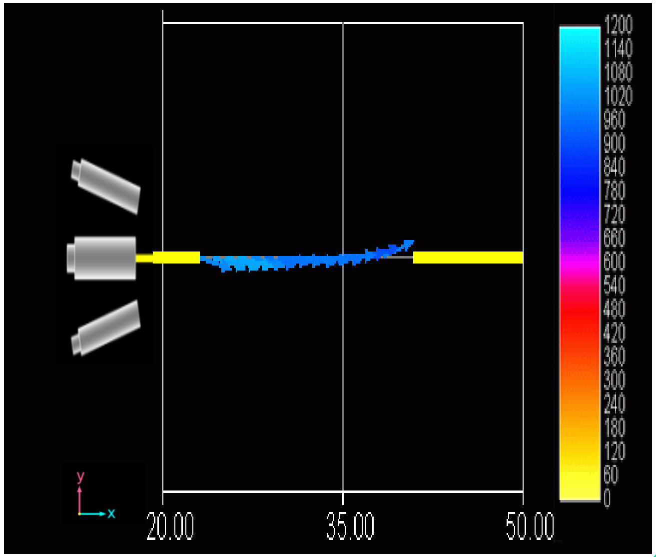
Flow of LBE

Experimental approach to observe LBE flow



JLBL-2

3-D monitoring of LBE flow by UVP

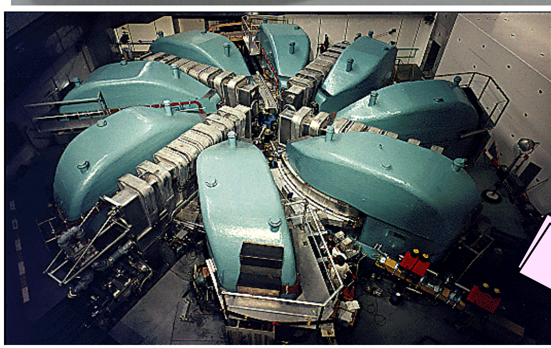


- It was confirmed that average heat transfer at the beam window can be calculated with good accuracy.
- Stability of the flow should be investigated in detail.
- Ultrasonic Velocity Profiling (UVP) is being developed.

International Program for LBE Target Demonstration : MEGAPIE

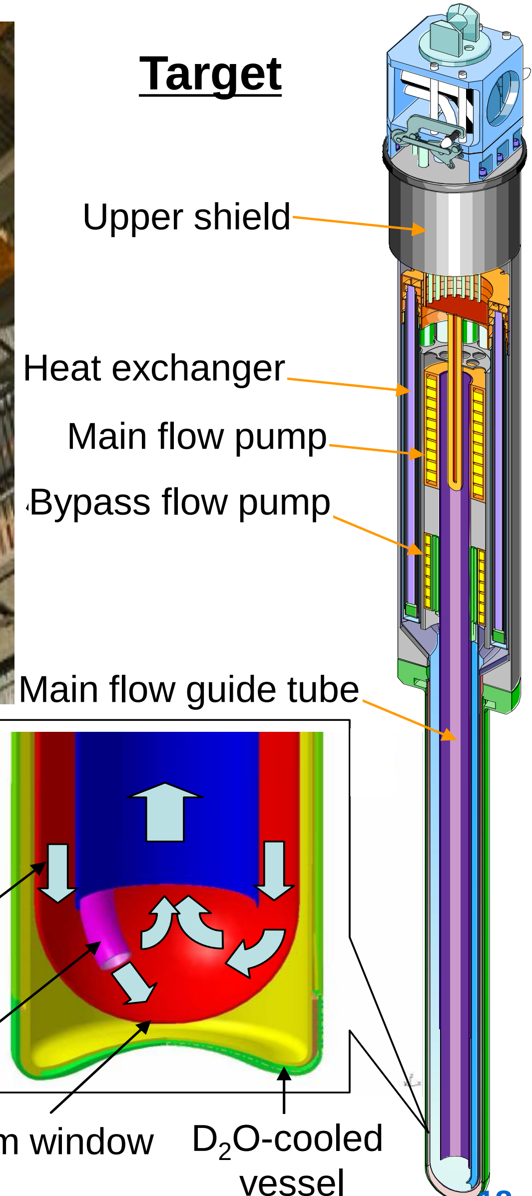
- An LBE target was installed in SINQ of PSI, Switzerland.
- Participants: Switzerland, France, Germany, Belgium, Italy, Japan, US, Korea.
- 4-month operation with 700kW (1.2mA X 590MeV) was successfully carried out.
- PIE is now being conducted in.

← Dummy specimen cut from mock-up target

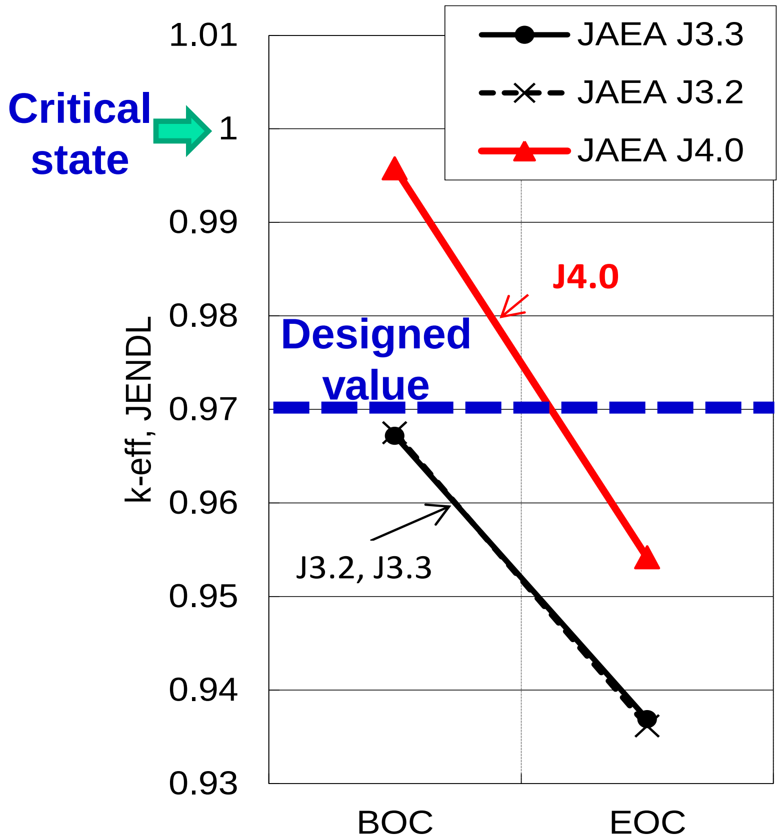


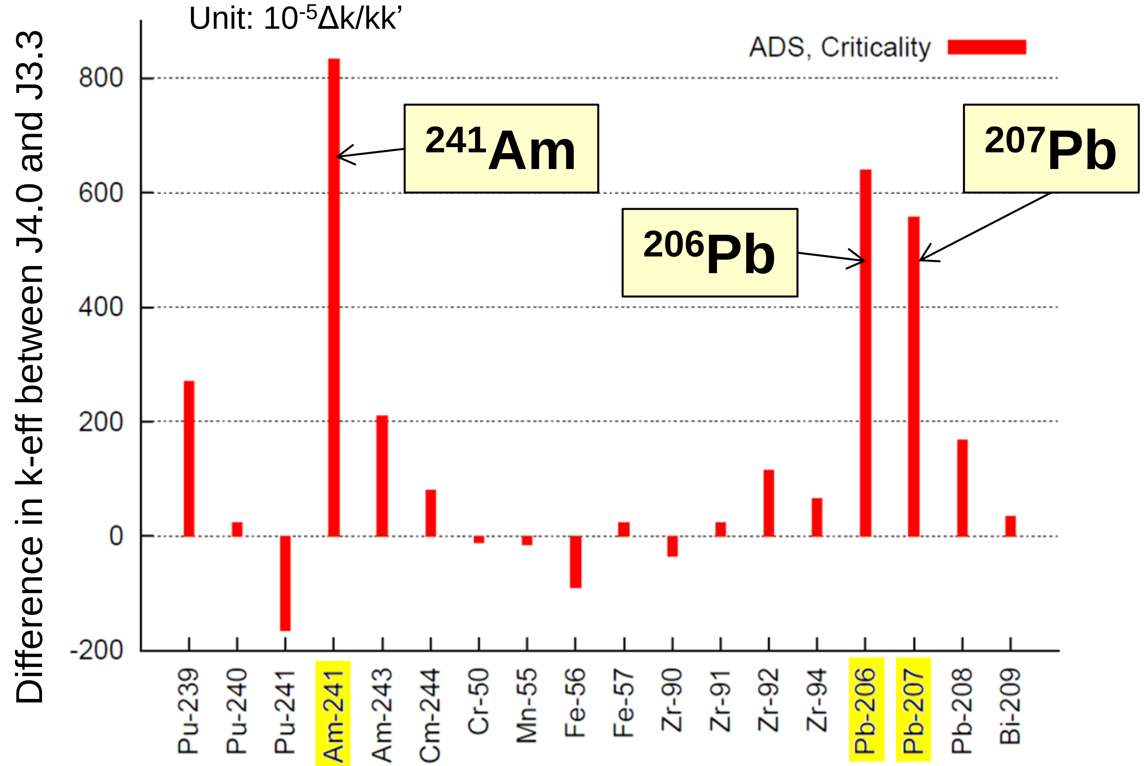
575MeV p- cyclotron

Proton beam



Accuracy of Neutronics Design

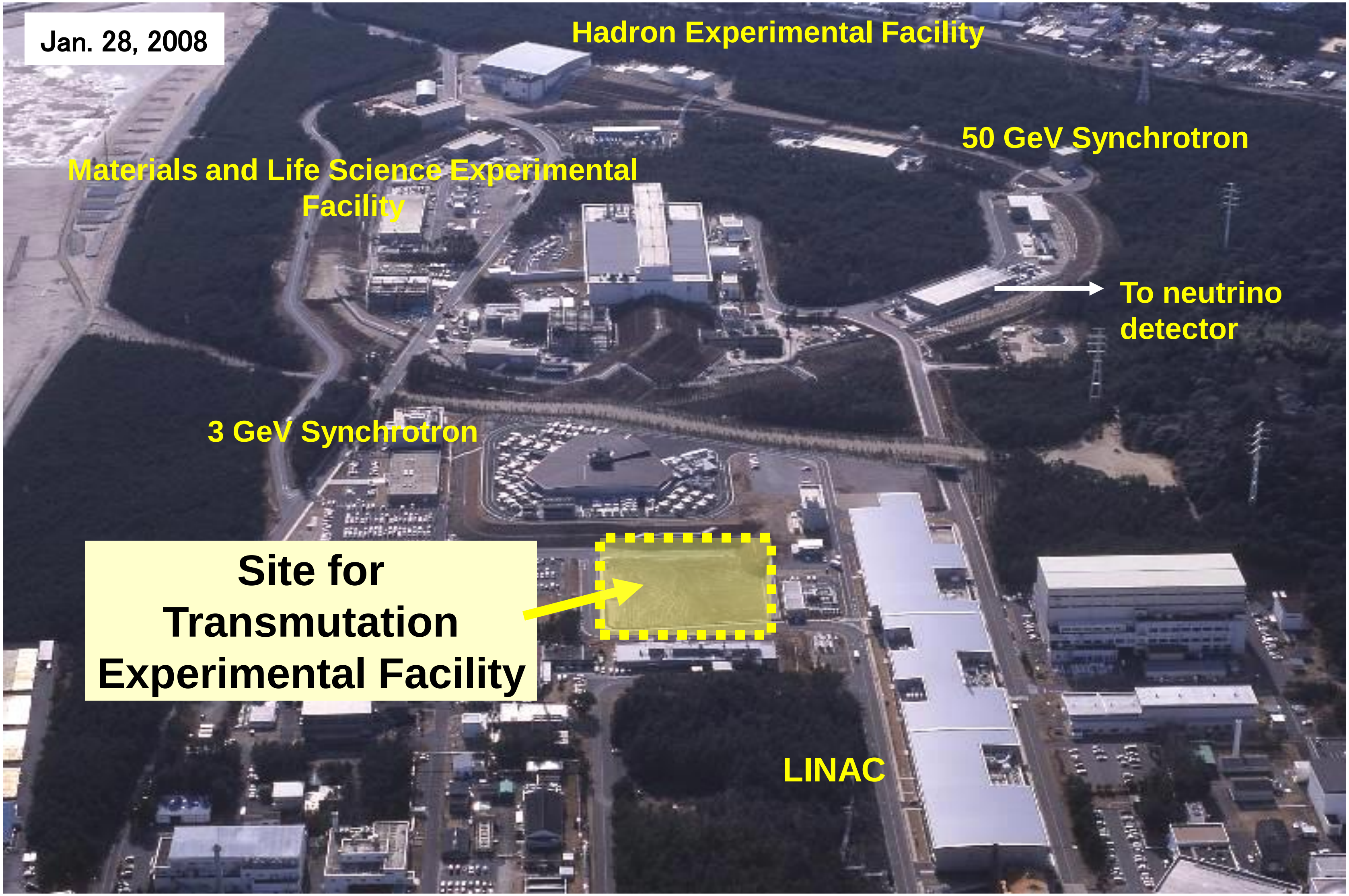




Benchmark calculation for 800MWt ADS for BOC and EOC.
(Left: Comparison between JENDL-4.0 and JENDL-3.3, Right: Nuclide-wise contribution for differences in k-eff)

- There is 2% difference in k-eff between JENDL-4.0 and JENDL-3.2, which is too large to design ADS. ➔ **necessity of integral validation of nuclear data**

Japan Proton Accelerator Research Complex: J-PARC



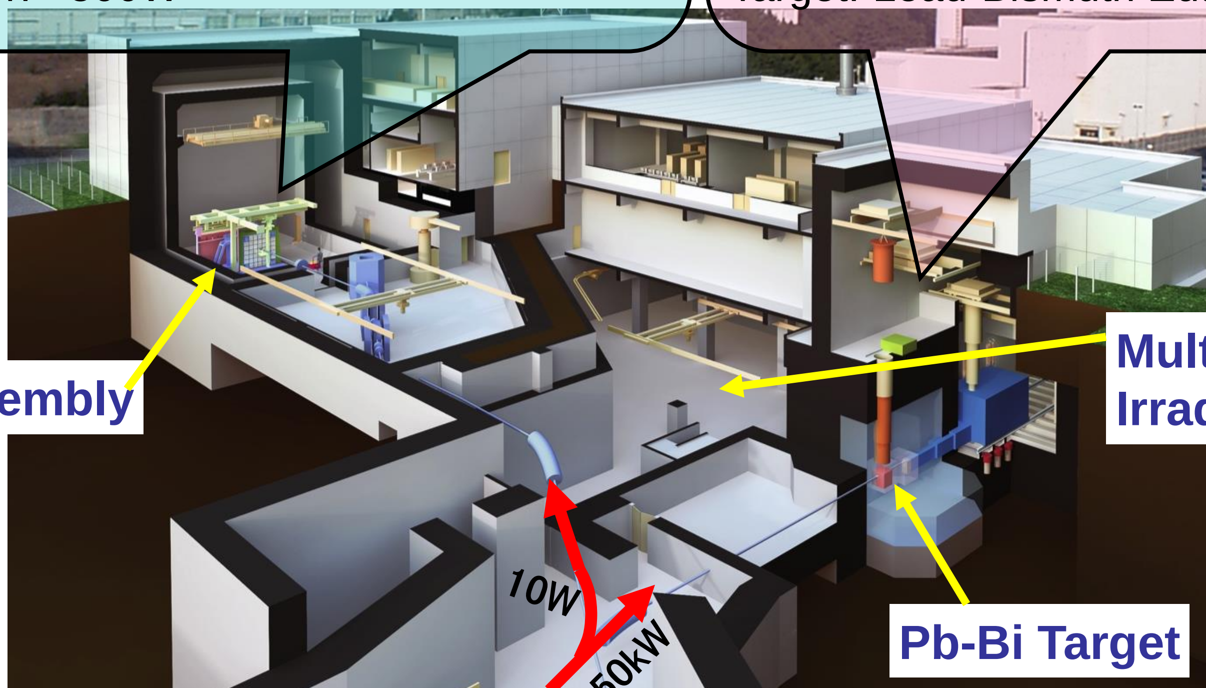
Plan of Transmutation Experimental Facility (TEF) as Phase-II of J-PARC

Transmutation Physics Experimental Facility: TEF-P

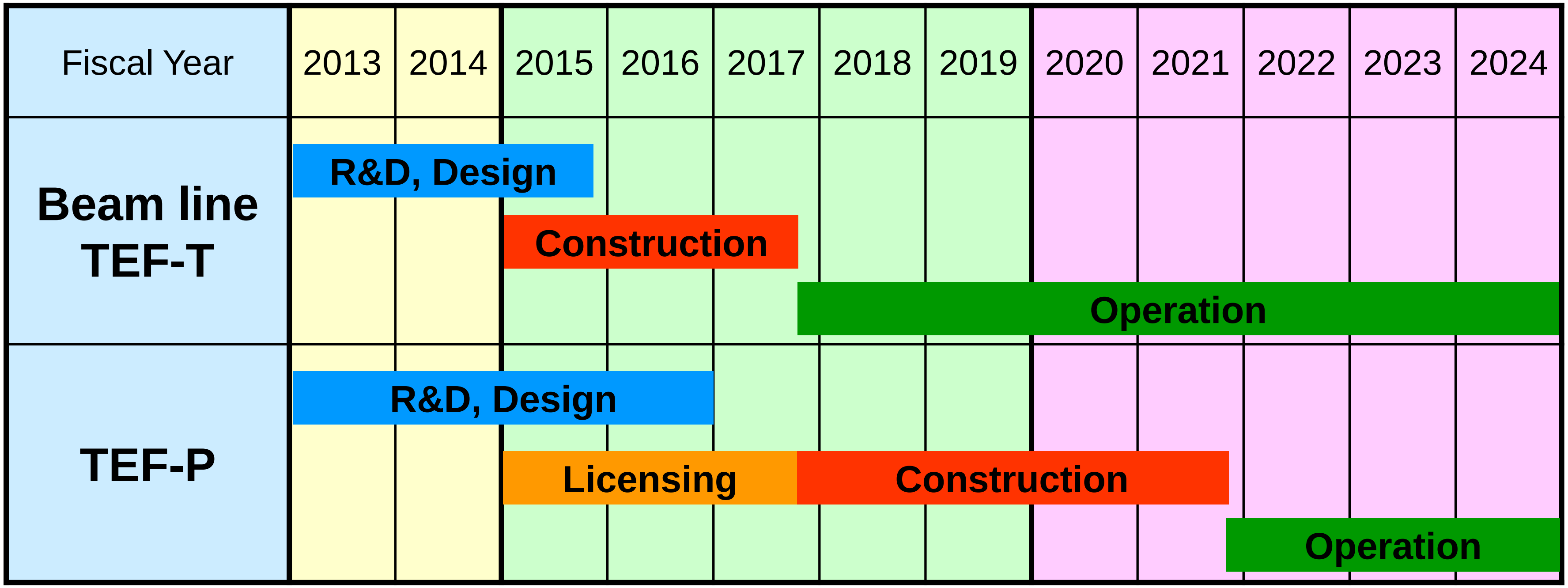
Purpose: To investigate physics properties of subcritical reactor with low power, and to accumulate operation experiences of ADS.
Licensing: Nuclear reactor: (Critical assembly)
Proton beam: 400MeV-10W
Thermal power: <500W

ADS Target Test Facility：TEF-T

Purpose: To research and develop a spallation target and related materials with high-power proton beam.
Licensing: Particle accelerator
Proton beam: 400MeV-250kW
Target: Lead-Bismuth Eutectic (LBE, Pb-Bi)



Preliminary Schedule of TEF



- The construction of Beam line and TEF-T will be started in 2015 and the operation will be started in 2017.
- To start the construction of TEF-P in 2017, just after the completion of TEF-T, a few years of licensing activities should be started in 2015.

Working Party to Review Partitioning and Transmutation Technology in Japan

JAEA

- The Ministry of Education, Culture, Sports Science and Technology (MEXT) in Japan has launched a Working Party to review Partitioning and Transmutation Technology in August, 2013.
- An interim report was issued in November, 2013.

Key Descriptions:

◆To reduce the burden of HLW management, it is expected that **flexibility in future political decision is extended** by showing possibilities of new concepts of back-end with high social receptivity.

◆The ADS Target Test Facility (**TEF-T**) is being proposed under J-PARC to verify the feasibility of the beam window. **It is appropriate to shift the R&D of the facility to the next stage**.

◆The Transmutation Physics Experimental Facility (**TEF-P**) is being proposed under J-PARC to overcome difficulties in reactor physics issues such as for a subcritical core and an MA-loaded one. Since this facility is proposed as a nuclear reactor, the **safety review by the new regulation** is to be applied. With taking care of this point, **it is appropriate to shift the R&D of the facility to the next stage**.

◆For **MYRRHA** Program, **it is appropriate to proceed with negotiation about JAEA's participation at a reasonable level and mutual collaboration** with Belgium and other relevant countries.

◆Progress of the development should be checked according to its stage.

Concluding Remarks

- ADS is a dedicated system for effective transmutation of MA.
- Fission reactions are necessary for MA transmutation, but nuclear data including FP yield are insufficient presently.
- J-PARC Transmutation Experimental Facility (TEF) is waiting for approval of construction from the Government.
  - TEF will consist of two facilities: TEF-T for LBE target development and TEF-P for physics experiments for science and technology of transmutation.
  - TEF-T can accept multi-purpose uses of a 400MeV proton beam and spallation neutrons.
- International and interdisciplinary collaboration is essential for this technology.